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6. AUTHOR(S)
Robert E. McIntosh

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University of Massachusetts
Elec. & Comp. Engr.
Knowles Engr. Bldg.
Amherst, MA 01003

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This AASERT grant provided graduate student support for one student, Stephen Frasier, working on the Focused Phased Array Imaging Radar (FOPAIR) program at the University of Massachusetts Microwave Remote Sensing Laboratory (MIRSL). During the reporting period, Steve conducted a number of field experiments to test and validate the radar system. These tests were held at Amherst, MA (UMass campus), N. Truro, MA (Cape Cod), La Jolla, CA (Scripps Institute of Oceanography), and Duck, NC (USACE/WES-FRF). Results of these tests have been published in four conference papers, two journal papers, and on Ph.D. dissertation.

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FINAL REPORT:
Study of Focused Phased Array Imaging Radar (FOPAIR) Techniques

ONR AASERT Grant: N00014-92-J-1697

Robert E. McIntosh, Principal Investigator

University of Massachusetts

Microwave Remote Sensing Laboratory

Amherst, MA 01003

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Contents

1. Introduction

This report summarizes research activities and results obtained by graduate students supported by ONR AASERT funding under grant N00014-92-J-1697 "Study of Focused Phased Array Imaging Radar (FOPAIR) Techniques" for the period June 1, 1992 to May 31, 1995. This grant provided graduate student support for one student, Stephen Frasier, working on the FOPAIR program at the University of Massachusetts Microwave Remote Sensing Laboratory (MIRSL). Early in the reporting period, construction of the FOPAIR imaging radar was completed and a final report was submitted to ONR by Quadrant Engineering, Inc. (May 13, 1993). Concurrent with this, the radar system was turned over to MIRSL for subsequent system development and field operations. These activities are summarized in the following section.

2. Summary of Activities

2.1 Year 1: June 1, 1992 – May 31, 1993

Construction of FOPAIR was completed in March 1993. As MIRSL would be continuing development and operating the radar system, Steve was involved both in radar construction and in software development for radar control and subsequent data analysis during this early period. The first engineering tests of FOPAIR were performed in April 1993 on the UMass campus. For these tests, FOPAIR was deployed atop Tobin Hall where it could view an adjacent athletic field. A variety of targets, corner reflectors, people, etc. were observed and successfully imaged by the radar. An ocean imaging test was performed at North Truro, MA (Cape Cod) on May 5, 1993 at which both sponsors and collaborators were present. Though ocean and wind conditions were less than optimum, FOPAIR was able to image some breaking waves in the surf zone.

2.2 Year 2: June 1, 1993 – May 31, 1994

In July 1993, FOPAIR was deployed on the research pier at Scripps Institute of Oceanography (SIO) in La Jolla, CA. With support from Dr. Ken Melville, it was intended for FOPAIR to obtain ocean surface image data to prepare for future ocean measurements. In addition, it was intended that FOPAIR could obtain coordinated measurements with an imaging Doppler sonar also being tested at the SIO pier. Such coordinated measurements were prevented by intermittent hardware failures in the radar and sonar systems and in the pier's boat winch (required to deploy the sonar). While this was disappointing, a fair amount of radar data was obtained, and a number of problems were identified so that system improvements could be made prior to the next measurement. These included:

1. Debugged a manufacturing flaw in the I/O interface between the A/D converter and the disk system. This flaw caused the digitized radar samples to be intermittently skewed in position

2. Improved the tape backup software, reducing the turn-around time between acquisitions by more than a factor of two.

3. Upgraded the digital control of the radar to support more flexible triggering permitting unambiguous Doppler measurements (through pulse-pair techniques) with reduced overall frame rates. This would allow for longer sampling times.

4. Fabricated a higher gain transmitting antenna for near-grazing applications where small elevation-plane patterns could be tolerated.

The next deployment occured in November 1993 at the U.S. Army Engineers' Field Research Facility (FRF) Pier at Duck, NC. Here, FOPAIR was deployed on the pier looking northward in an attempt to observe longshore currents. FRF staff deployed an instrumented "sled" in the field-of-view to directly measure currents. A metallic vertical mast on the sled turned out to generate substantial interference in the radar imagery. In addition, other sources of interference were observed and presumed to be due to structures on the shore observed through grating lobes.

Analysis of the data obtained from the SIO and Duck deployments occured during the winter months and provided a basis for planning an experiment in the Spring of 1994. From the image data obtained at SIO, Steve compared Doppler measurements of individual pixels to wire wave-gauge (non-directional) measurements and found good agreement. It had been anticipated that FOPAIR should be capable of measuring a directional spectrum. In the November Duck deployment, Steve contacted Dr. Chuck Long who operates the directional wave array at the FRF, a device was capable of independent directional spectrum measurement to which FOPAIR measurements might be compared. In March 1994, an additional deployment at Duck was performed where direct comparison of directional wave measurements made by FOPAIR and the FRF-array were attempted. Analysis of these data occured through the end of the second year reporting period. Steve presented results obtained earlier at the 1994 URSI Commission-F Microwave Specialist Symposium in Lawrence, KS on May 5, 1994.

2.3 Year 3: June 1, 1994 – May 31, 1995

Analysis for the directional wave spectrum comparision continued through June, and results were submitted for publication in July 1994. In addition to the wave spectrum analysis, Steve investigated a technique for self-calibrating the array in the field without the need for a calibrating point-source such as a corner reflector. He completed and defended his doctoral dissertation entitled "A Focused Array Imaging Radar for Ocean Remote Sensing"

in August, and was awarded his degree on September 1, 1994. The dissertation outlined FOPAIR's design, field calibration and antenna sidelobe issues, and included the directional wave spectrum comparision. In August, he presented a poster summarizing FOPAIR data results at IGARSS'94 in Pasadena, CA, and in late September, he presented a summary of the FOPAIR hardware at the 1994 Antenna Applications Symposium at Robert Allerton Park in Monticello, IL.

Steve has stayed on at MIRSL in the position of research engineer and continues to work on the FOPAIR project overseeing activities of two graduate students, Yong Liu and Delwyn Moller. He has most recently extended the 2-D spectrum analysis to full 3-D (wavevector-frequency) spectra of radar backscatter. Data obtained during the March 1994 deployment exhibits effects in the spectra due to longshore currents and to non-Bragg scatterers. This is to be presented at IGARSS'95.

During October 1994, FOPAIR was again deployed at Duck, NC "piggybacking" on the DUCK'94 Nearshore Field Experiment. Measurements were made here of the nearshore zone as FOPAIR was constrained to operate shoreward of the FRF's "Sensor Insertion System" which moved up and down the pier throughout the experiment. A substantial amount of instrumentation was deployed in the nearshore zone for profiling longshore and cross-shore currents (among other things). Detailed analysis of the radar data is yet to be completed, though much of it is likely contaminated by large-scale breaking waves that often saturated the radar receiver. In addition, some coordinated measurements were made with an Ultra Wideband Radar (UWB) operated by Dr. Mark Sletten of NRL. Graduate student Delwyn Moller will analyze these data.

Up to this point, the most useful measurements of backscattered power and Doppler velocity have been obtained using only half of the receiving array at a time (due to constraints in the data acquisition system). Because of this, it was decided to modify half of the array from vertical to horizontal polarization. With the addition of another transmitting antenna, FOPAIR is now a dual-polarized imaging radar. Such modifications were completed in time for FOPAIR's deployment aboard the R/P FLIP in April-May 1995 for ONR's Marine Boundary Layer ARI. Graduate student Yong Liu obtained dual-polarized backscatter data for several weeks during this open ocean experiment. He is currently analyzing his results.

3. Summary of Publications

3.1 Journal Papers

1. McIntosh, R.E., S.J Frasier, J.B. Mead, "FOPAIR: A Focused Phased Array Imaging Radar for Ocean Remote Sensing", *IEEE Transactions on Geoscience and Remote Sensing*, V 33, N 1, pp 115–124, Jan, 1995.

2. Frasier, S.J., Y. Liu, D. Moller, R.E. McIntosh, C. Long, "Directional Ocean Wave

Measurements in a Coastal Setting Using a Focused Array Imaging Radar", *IEEE Transactions on Geoscience and Remote Sensing*, V 33, N 2, pp 428–440, Mar, 1995.

3.2 Dissertations

1. Frasier, S.J., "A Focused Array Imaging Radar for Ocean Remote Sensing", Ph.D. Dissertation, University of Massachusetts Amherst, September 1994, 119 pages.

3.3 Conference Papers

1. Frasier, S.J., R.E. McIntosh, "Ocean Surface Observations using Focused Phased Array Imaging Radar", presented at 1994 URSI Commission-F Microwave Specialist Symposium, Lawrence, KS, May 1994.

2. Frasier, S.J., Y. Liu, R.E. McIntosh, "Ocean Surface Imaging with a Focused Phased Array Imaging Radar", presented at 1994 International Geoscience and Remote Sensing Symposium (IGARSS'94), Pasadena, CA, August 1994.

3. Frasier, S.J., J.B. Mead, R.E. McIntosh, "A Digitally Focused X-Band Imaging Array", presented at 1994 Antenna Applications Symposium, Allerton Park, Monticello, IL, September 1994

4. Frasier, S.J., R.E. McIntosh, "Three Dimensional Analysis of X-Band Doppler Radar Backscatter from the Ocean Surface", to be presented at 1995 International Geoscience and Remote Sensing Symposium (IGARSS'95), Florence Italy, July 1995.